EFFECTS OF INCREASED INLET-GUIDE-VANE-ROTOR SPACING ON COMPRESSOR NOISE REDUCTION

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Presented at the Seventy-Second Meeting of the
Acoustical Society of America

FACILITY FORM 602

N68-27443 (ACCESSION NUMBER) — (THRU)

15 (PAGES) — 1 (CODE)

TMX-59214 (NASA CR OR TMX OR AD NUMBER) — 28 (CATEGORY)

Los Angeles, California
November 2-5, 1966

GPO PRICE $ ____________

CFSTI PRICE(S) $ ____________

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

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ABSTRACT

One of the sources of compressor noise is the fluctuating aerodynamic loadings resulting from interactions between the fixed and rotating blades. Studies involving a model single-stage compressor have shown that an increased axial spacing between the components of the compressor resulted in substantial reductions of the pure tone noise. Based on the above experience, the inlet guide vanes of a turbojet engine in the 2,000 pound thrust range were relocated forward about six chord lengths with the objective of reducing noise. Comparisons are made of the noise characteristics of the above simply modified engine with those of the basic engine. The compressor noise levels for the modified engine are shown to be greatly reduced, for all frequencies, with no measurable performance loss.

INTRODUCTION

One of the principal components of noise in jet engines is due to the aerodynamic interactions of the fixed and rotating compressor blades. A schematic diagram of the noise spectrum from a jet engine is shown in figure 1 to illustrate the nature of its principal components. Both broad-band and discrete frequency noise components are present. Although the broad-band noise may in some situations be important, the discrete frequencies as indicated by the heavy vertical lines are generally the most objectionable subjectively. The reduction of these pure tones is the subject of the present paper.

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The sources of these pure tones are believed to be the fluctuating forces resulting from the aerodynamic interactions of the fixed and rotating compressor blades. Figure 2 contains schematic diagrams which illustrate some of the main features of the aerodynamic wakes of stator vanes and the resulting load fluctuations on the rotor blades (refs. 1, 2, and 3). The upper diagram shows air flow over a stationary blade. There is a defect in velocity in the wake as indicated by the dark shaded regions. The velocity defect is strongest near the trailing edge of the stationary blade where the wake is narrowest. As the wake broadens out at greater distances downstream, the velocity deficiency decreases. Thus as seen in the middle diagram, a rotor passing through the wake of the stationary blade (inlet guide vanes) will encounter different flow conditions depending on the portion of the wake it encounters. As the rotor blade passes through the wake, it experiences a momentary change in angle of attack due to the variation in in-flow velocity, and thus there is an associated fluctuation in the blade loading. Although the detail nature of this fluctuati l has not at present been defined, the diagram at the bottom of the f serves to indicate the kind of pulsations one might expect due to the load fluctuation. It can be seen that when the inlet guide vanes are a greater distanc upstream of the rotor, the load fluctuation becomes smaller.

RESULTS FROM MODEL SINGLE-STAGE COMPRESSOR

Figure 3 shows some beneficial results in the form of noise radiation patterns for a single-stage compressor on which the I.G.V. were located at two different distances relative to the rotor. The curve of circle data points represents the condition in which the I.G.V. were nearest to the rotor.

The curve of diamond data points represents the condition in which the I.G.V. were upstream of the rotor a distance of 6.25 chord lengths. It can be seen that there is a substantial reduction in noise due to the increased clearance.

Figure 4 shows some results of the effect of stator vanes downstream of the rotor. The curve of triangle data points represents the I.G.V.- rotor-stator combination with a minimum I.G.V.-rotor separation. This curve is seen to differ only slightly from the circle data curve of figure 3 for which the I.G.V. were nearest the rotor. The curve of diamond data points of figure 4 represents the I.G.V.-rotor-stator combination in which the I.G.V. were upstream of the rotor a distance of 6.25 chord lengths. Again, as shown in figure 3, it is seen that there is a substantial reduction in noise due to the increased clearance.

Results of model investigations have consistently shown noise reductions due to increased I.G.V.-rotor spacing. The next logical step was to demonstrate this beneficial effect of increased spacing on the multi-stage compressor of a turbojet engine

RESULTS FROM FULL-SCALE MULTI-STAGE COMPRESSOR

Test Setup

A sketch of a turbojet engine which was modified is shown in figure 5. This sketch includes a cut-away section of several stages of the compressor. The first stage rotor had 29 blades with a mean chord of 1-1/2 inches and the I.G.V. assembly had 41 vanes with a constant chord of one inch. It can be seen from this sketch how the I.G.V. were moved upstream as a modification for the purpose of this test. The basic engine had the I.G.V. approximately one-eighth rotor blade mean chord length upstream of the rotor. The three

struts, located 120° apart, were approximately two rotor blade mean chord lengths upstream of the rotor. These struts had a constant chord of approximately four rotor blade mean chords. The struts remained in the same position relative to the rotor when the I.G.V. were relocated upstream approximately five rotor blade mean chords. The engine was operated at speeds from 35 percent to 100 percent rated rpm for both the basic and modified configuration.

Aerodynamic Performance Data

Figure 6 is a plot of operating performance data for both the basic and modified engines over the range of rpm operated. The curve on the left is the compressor outlet pressure as measured over a range of speeds from 35 percent to 100 percent rated rpm. The compressor outlet pressure for the modified engine is at least equal to that of the basic engine for the speed range from 35 percent up to 80 percent rated rpm, and for the speed range above 80 percent rated rpm the outlet pressure tends to increase slightly for the modified engine. The curve on the right of the figure is the engine thrust as measured over the range of speed from 35 percent to 100 percent rated rpm. These data show a slight increase in thrust for the modified engine over the entire speed range. From data such as these, it can be seen that there is no measurable performance loss when this engine is modified to accommodate increased I.G.V.-rotor spacing.

Noise Radiation Patterns

The acoustic data presented is in the form of radiation patterns and frequency spectra for the engine operating at 80 percent rated rpm. In figure 7 are plotted radiation patterns for the overall noise levels as a function of azimuth angle. The circle symbols are data for the basic engine

and the square symbols are data for the modified engine. Both sets of data suggest nearly uniform radiation patterns. It is readily seen that there is a substantial noise reduction at all azimuth angles for the modified engine due to the increased I.G.V.-rotor spacing. Even though there is a marked reduction in the overall noise levels, it is also important to know how the fundamental blade passage frequency has been affected by the increased spacing.

Figure 8 shows the effect of increased spacing on the noise levels of the fundamental blade passage frequency in the form of 1/3-octave band radiation patterns. Data are again presented for the basic engine and for the modified engine. It is readily seen that these latter curves are less uniform than those of the overall noise level data (See ref. 4.). Again the most obvious result is that substantial noise reductions occur due to increased I.G.V.-rotor spacing.

Noise Spectra

It was stated at the beginning of the paper that the pure tone noise was the most objectionable subjectively. Therefore, to illustrate what has been done to reduce the levels of these pure tones, figure 9 has been prepared. In this figure are plotted the frequency spectra for the basic engine and the modified engine. The spectrum for the basic engine (solid line) shows two distinct peaks, the first being the first stage rotor fundamental blade passage frequency and the second being the first stage rotor second harmonic. The spectrum for the modified engine (dashed line) has been included to show the beneficial effects of increased I.G.V. rotor spacing on the frequency apectrum. Although there is a distinct peak in the spectrum for the modified engine, this peak has been greatly reduced and the second harmonic peak has been eliminated. Also of interest is the fact that the broad-band noise

has been reduced substantially due to the I.G.V.-rotor spacing (See also ref. 5.).

CONCLUDING REMARKS

Increased clearance between the inlet guide vanes and rotor, which gave marked noise reductions for a single-stage model compressor, has also been applied to a turbojet engine. The required modifications, which resulted only in the movement of the inlet guide vanes, also produced substantial reductions in the front end noise of the turbojet engine and with no measurable decrease in engine performance.

REFERENCES

1. Crigler, John L.; and Copeland, W. Latham: Noise Studies of Inlet-Guide-Vane-Rotor Interaction of a Single-Stage Axial-Flow Compressor. NASA TN D-2962, 1965.
2. Copeland, W. Latham; Crigler, John L.; and Dibble, Andrew C., Jr.: Contribution of the Downstream Stator to the Interaction Noise of a Single-Stage Axial-Flow Compressor. Proposed NASA TN.
3. Crigler, John L.; and Copeland, W. Latham: Experimental Noise Studies of Inlet-Guide-Vane-Rotor-Stator Interactions for a Single-Stage Axial-Flow Compressor. Presented at the 70th meeting of the Acoustical Society of America (St. Louis, Missouri) November 3-6, 1965.
4. Tyler, J. M.; and Sofrin, T. G.: Axial-Flow Compressor Noise Studies. SAE Aeronautic Meeting, 1961, Preprint No. 345D.
5. Sharland, I. J.: Sources of Noise in Axial Flow Fans. Journal of Sound and Vibration, vol. 1, no. 3, pp. 302-322, 1964.

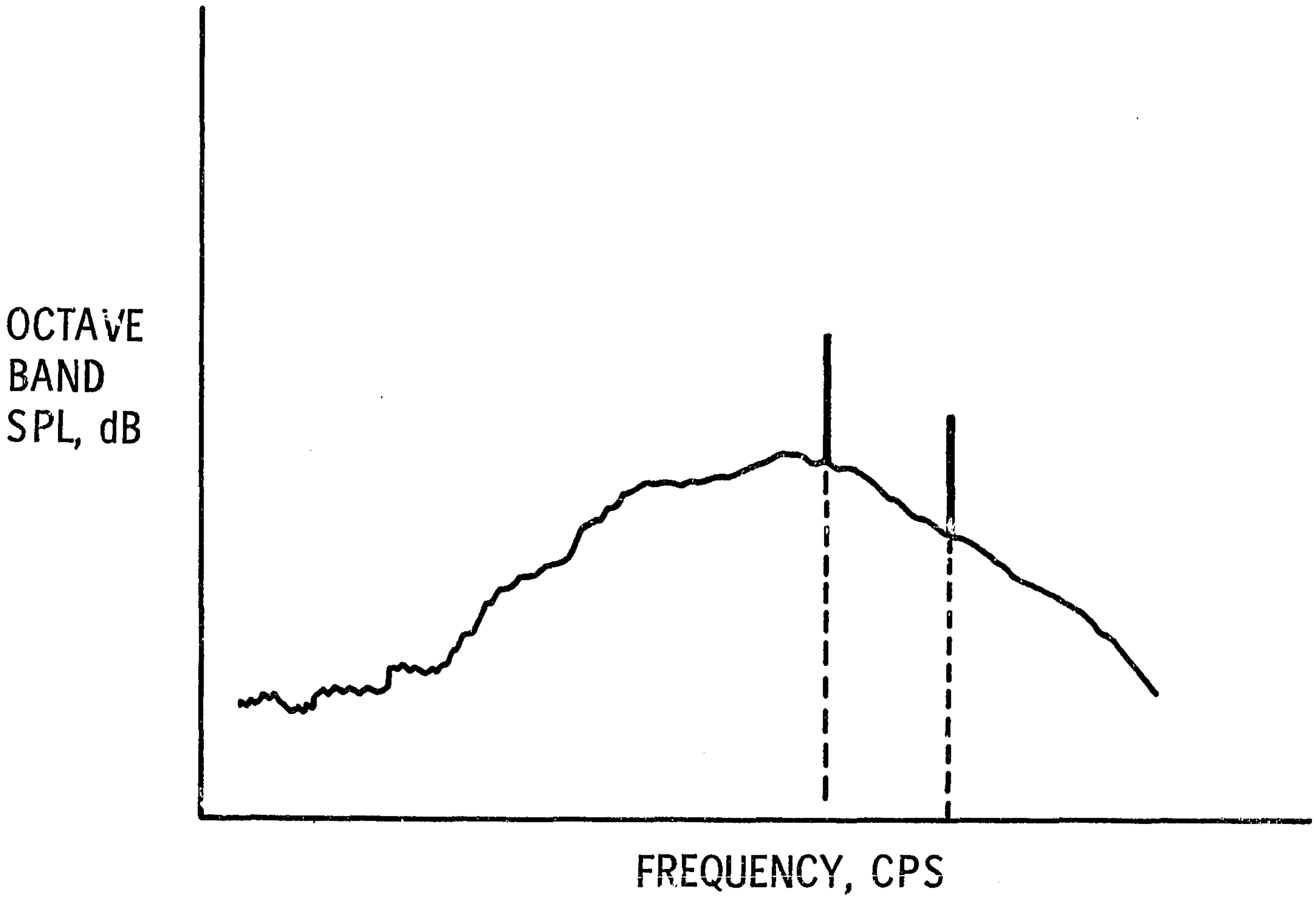

Figure 1.- Schematic of jet engine noise spectrum.

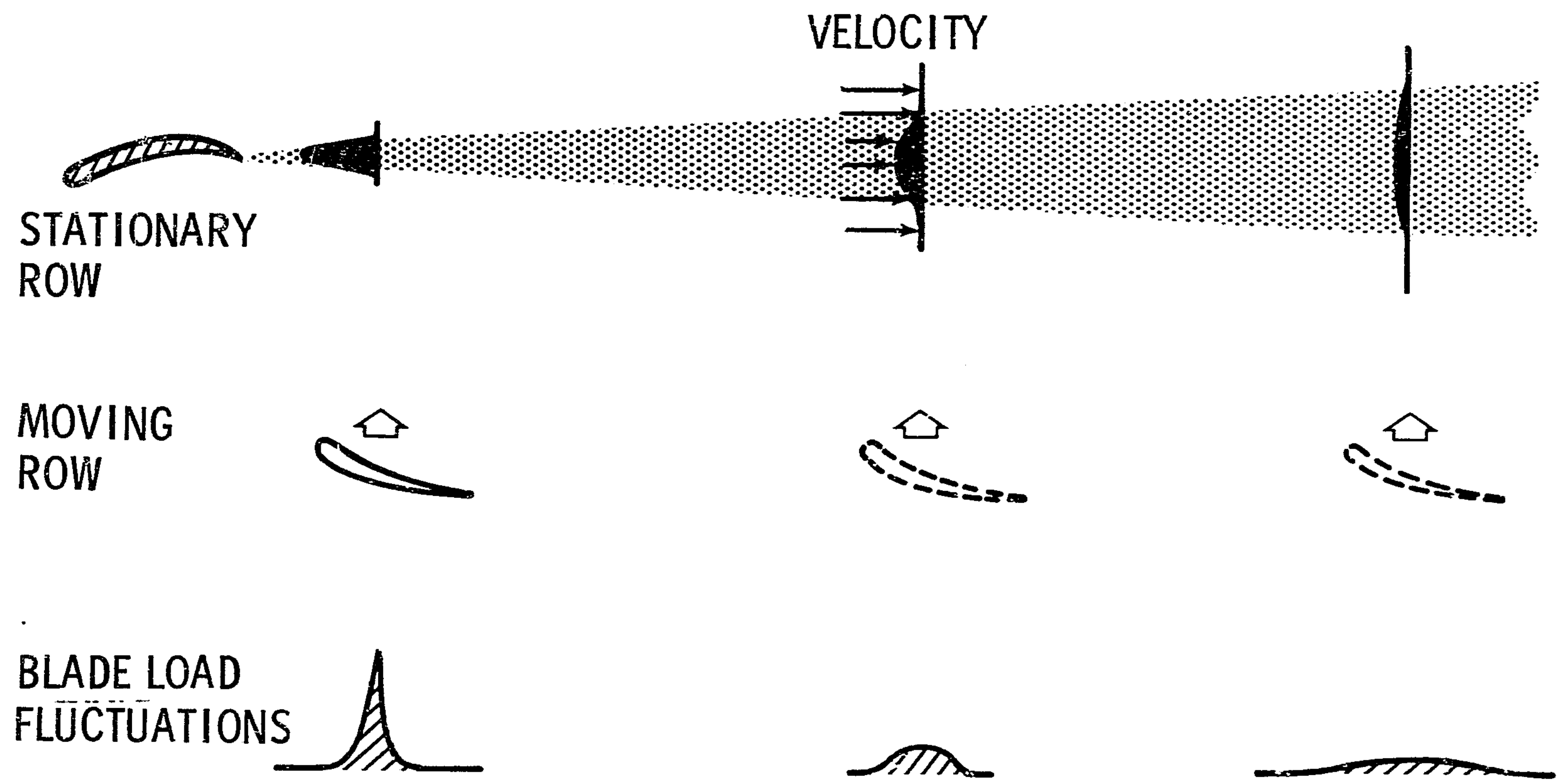

Figure 2.- Nature of inlet-guide-vane rotor interactions.

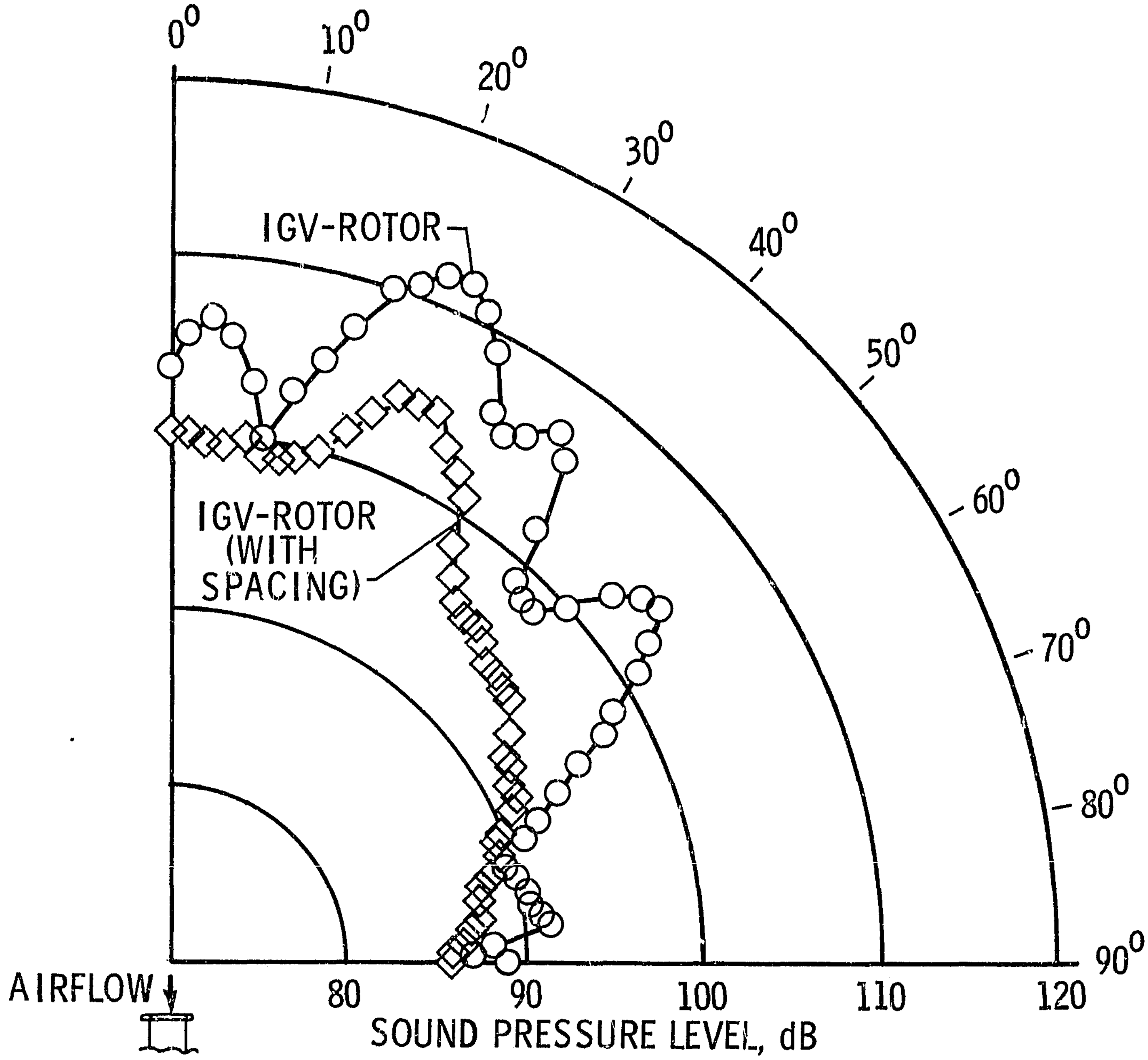

Figure 3.- Effect of spacing on IGV-rotor noise radiation patterns.

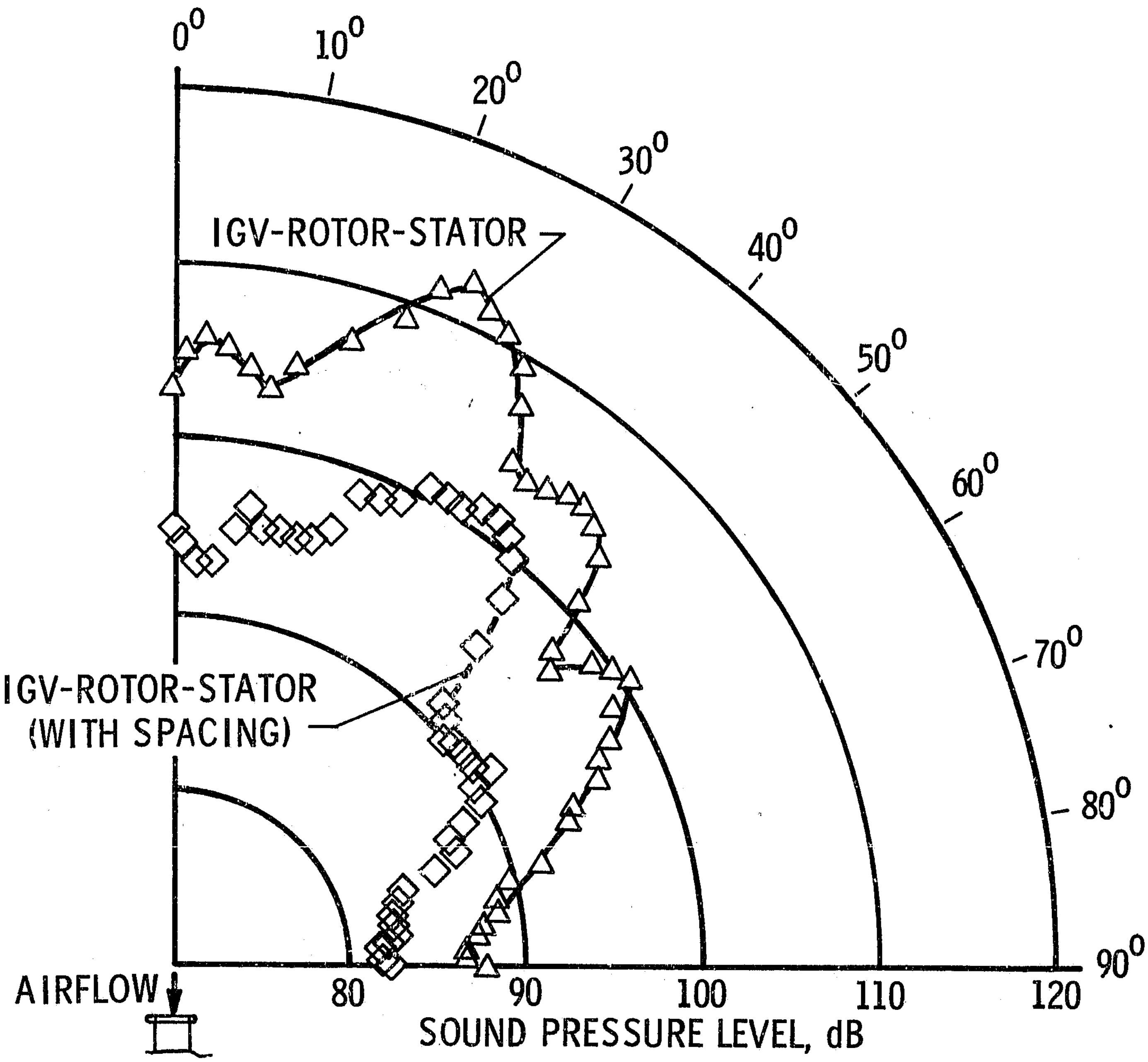

Figure 4.- Effect of spacing on IGV-rotor-stator noise radiation patterns.

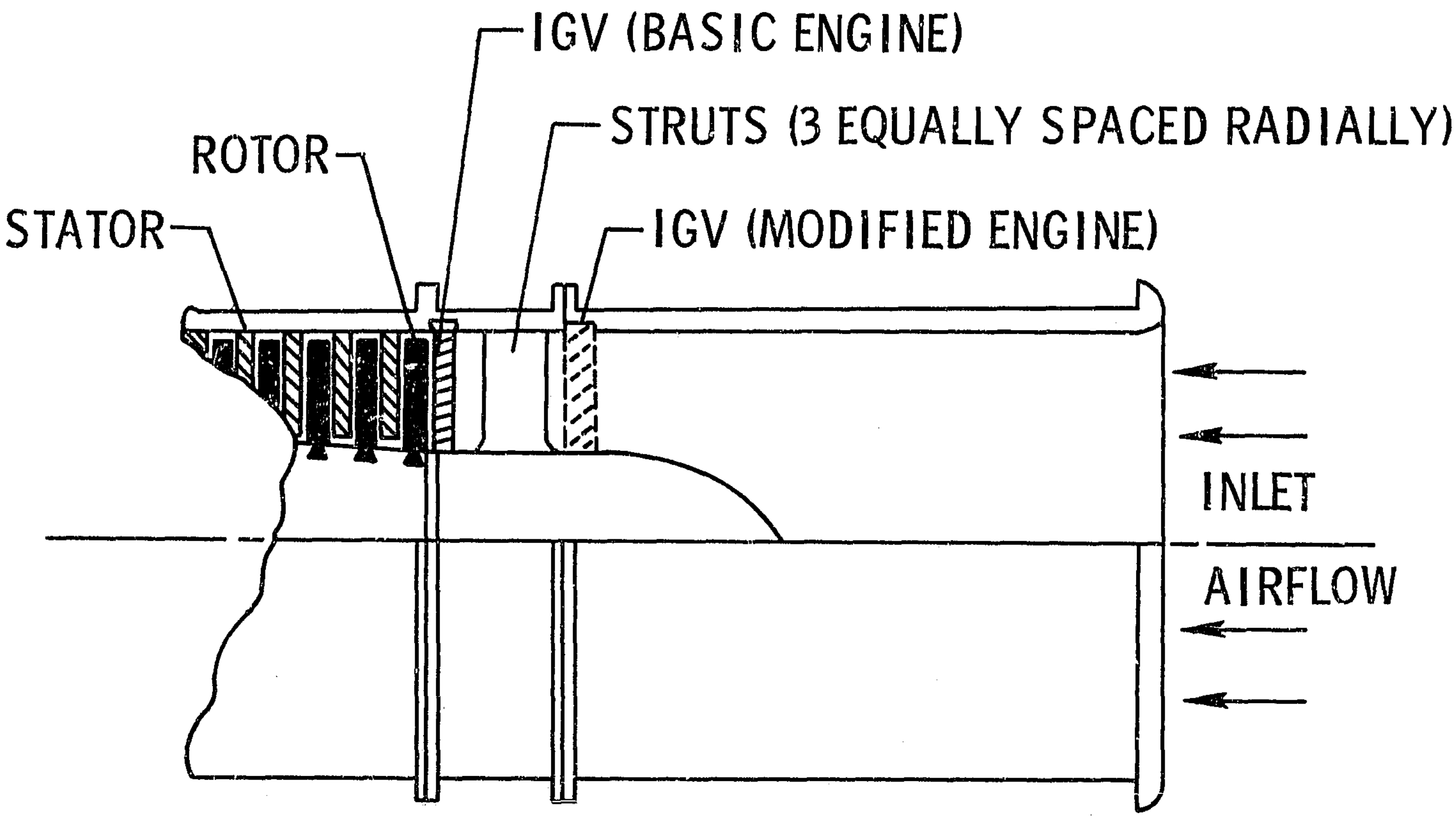

Figure 5.- Section cutaway schematic of compressor.

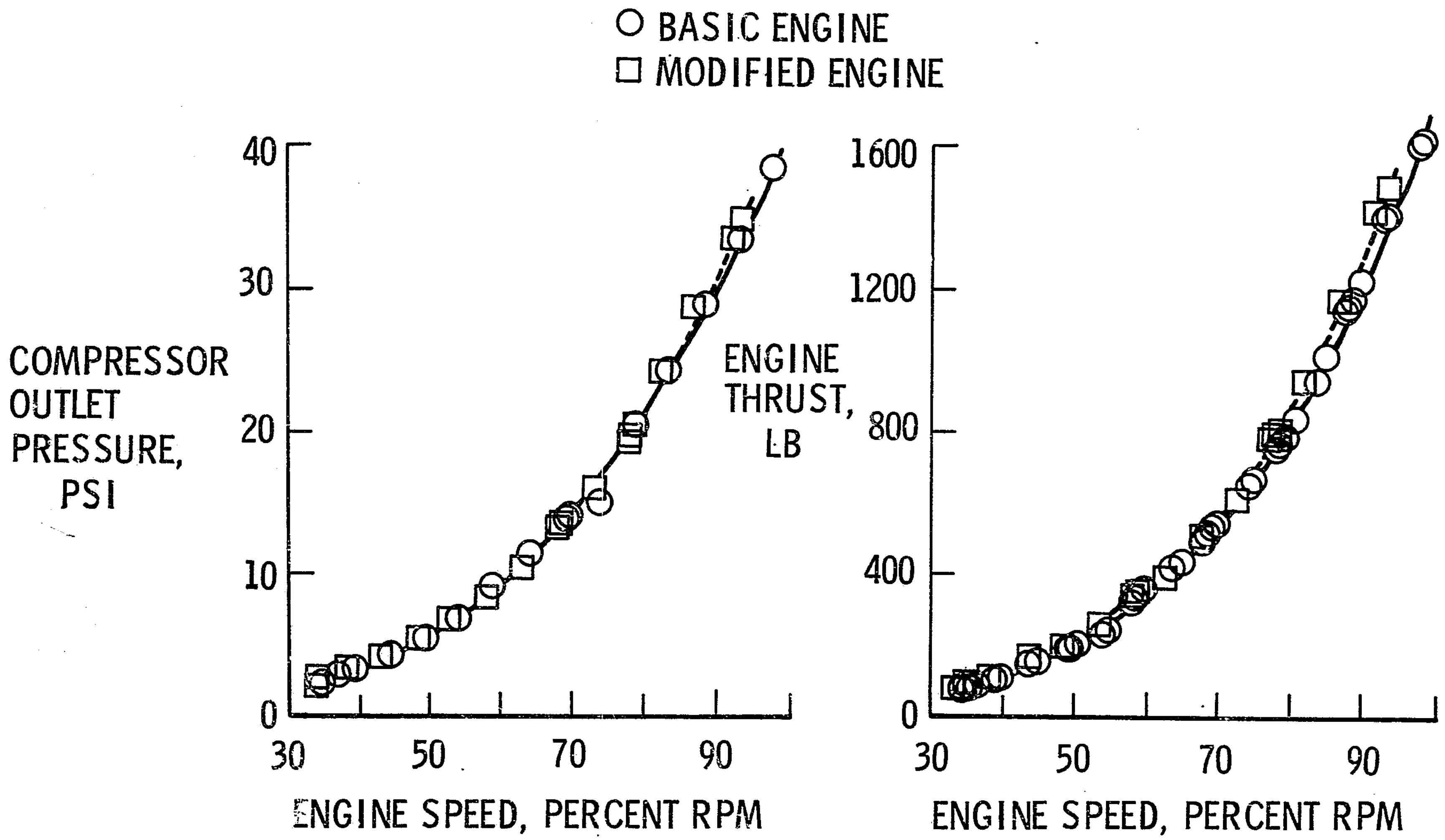

Figure 6.- Comparison of engine performance.

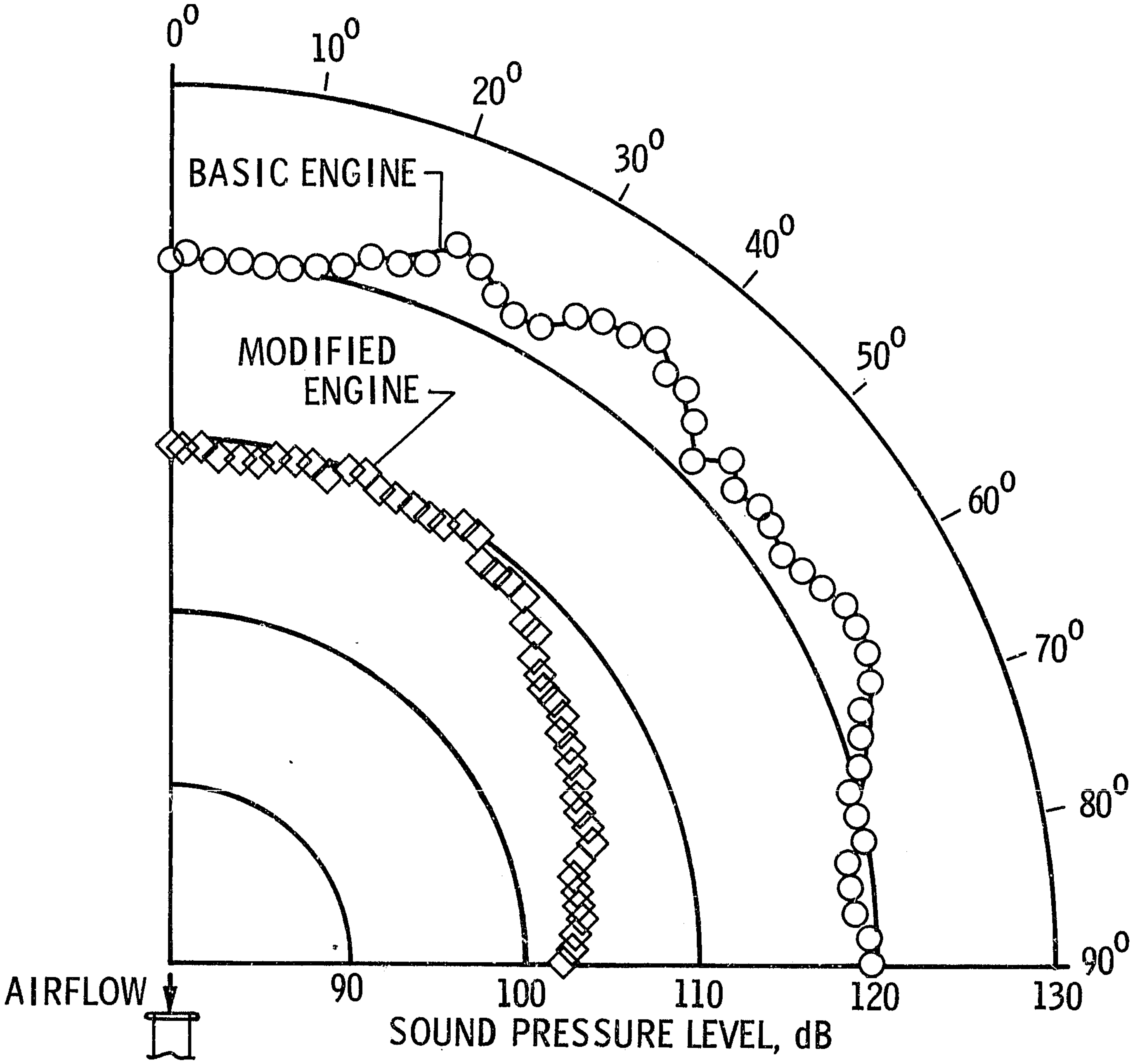

Figure 7.- Effect of spacing on overall noise radiation pattern.

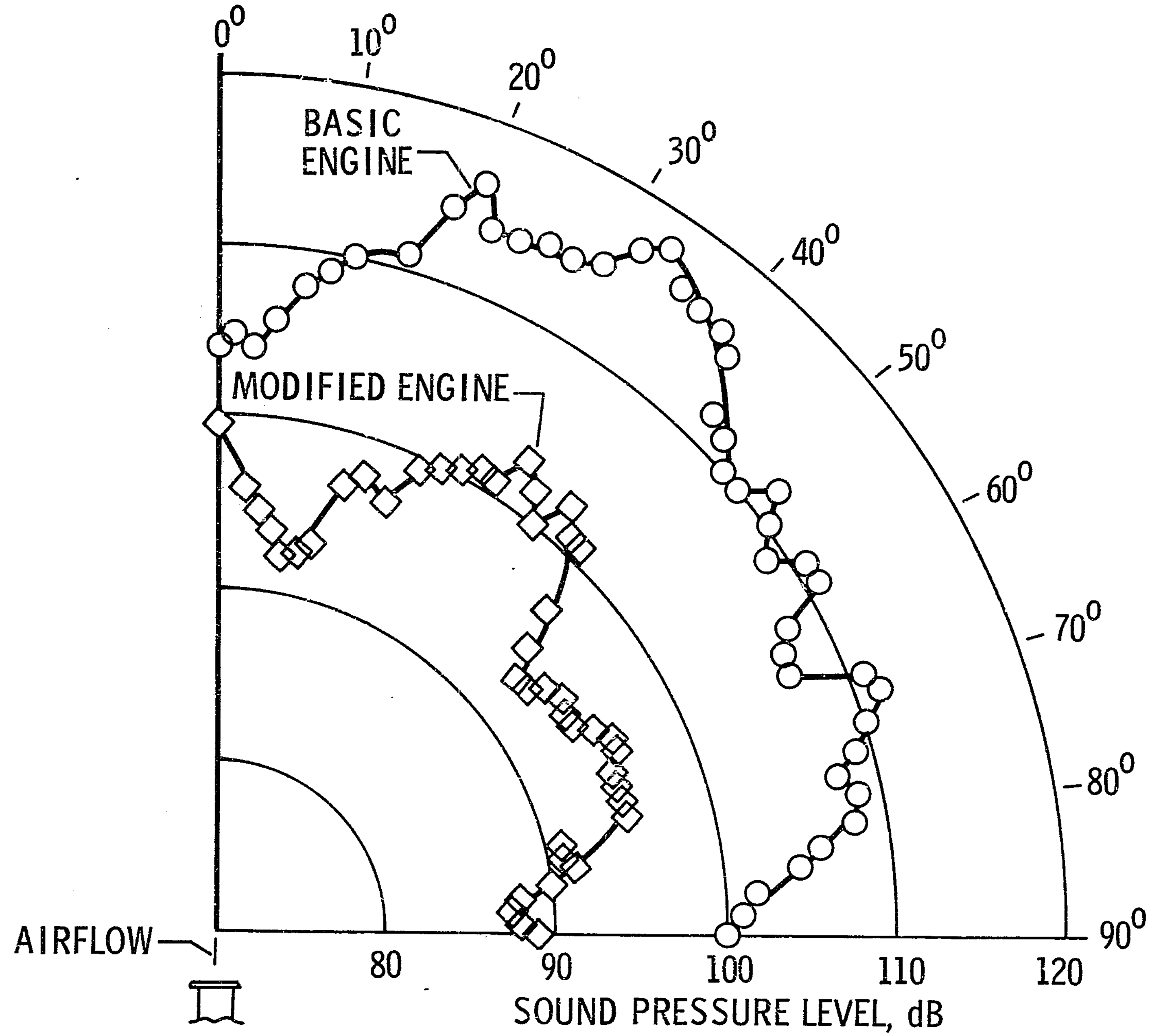

Figure 8.- Noise radiation patterns of fundamental blade frequency showing effect of spacing.

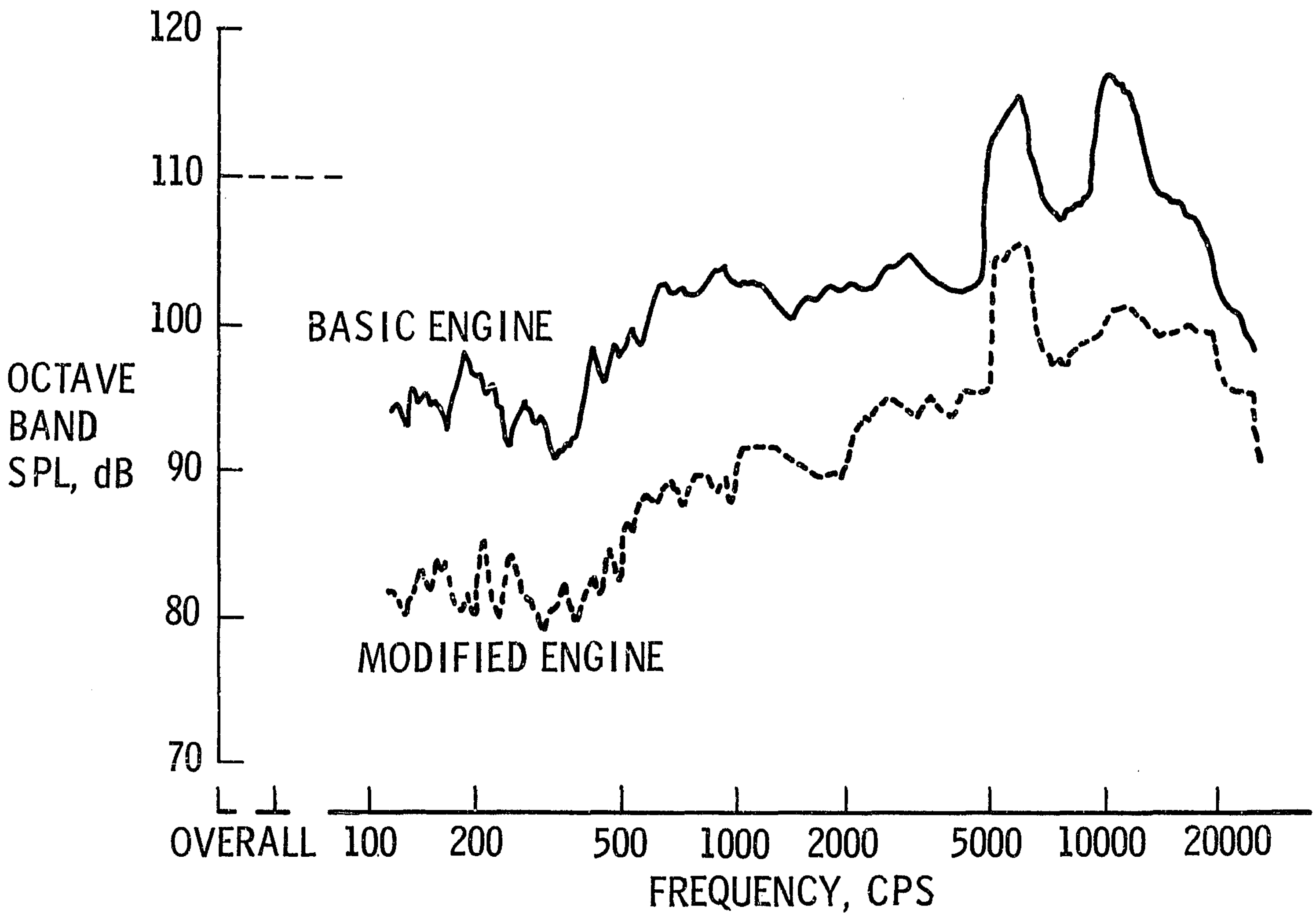

Figure 9.- Effect of spacing on compressor noise spectrum.

NASA-Langley, 1966